Competency 1.31 **EH Residents shall demonstrate a familiarity level knowledge of the systems and components for radiation detection, exposure monitoring, and contamination monitoring.**

1. SUPPORTING KNOWLEDGE AND/OR SKILLS

a. Discuss the operation and application of continuous air monitors (CAMs) and area radiation monitors (ARMs).

b. Discuss the following exposure monitoring dosimetry:
   - Internal dosimetry
   - External dosimetry
   - Nuclear accident dosimetry

c. Discuss the operation and application of process radiation monitors.

d. Discuss the operation and application of personnel contamination monitors (automated and hand-held).

2. SUMMARY

The EH resident's responsibilities generally include verifying ES&H programs; maintaining onsite presence to observe ES&H practices in the workplace; and serving as the EH point-of-contact, the EH resident duty officer, and subject matter/technical expert for site-related activities as assigned.

To assist the EH resident in his/her duties, several sources of information provided by the DOE should be utilized. For example, 10 CFR 835, *Occupational Radiation Protection*, requires monitoring of individuals and areas under Subpart E - Monitoring in the Workplace. Section 835.401 offers several valid reasons why such monitoring must be performed. Among these are the:

- Documentation of radiological conditions in the workplace;
- Observation of changes in radiological conditions;
- Detection of a general buildup of radioactive material;
- Verification of the effectiveness of engineering and process controls; and
- Identification and control of potential sources of personnel exposure to radiation and/or radioactive materials.

The DOE *Radiological Control Manual* offers detailed guidance for implementation of radiation protection in the DOE system. It establishes practices for the conduct of radiological control activities and states DOE's positions and views on the best courses of action currently available in the area of radiological controls. In particular, Chapter 2 (Part 2), Chapter 4 (Part 5) and Chapter 5 (Parts 1, 2, and 5) provide several recommendations useful in satisfying this competency.

NOTE: The *Radiological Control Manual* is intended to be reissued as a technical standard. The use of "shall" statements presently in the document will presumably be changed to "should" (or equivalent) statements. Regarding this radiation protection competency, statements referenced from the *Radiological Control Manual* employing the word "shall" have been modified to "should" or similar wording to reflect the shift in emphasis from a regulatory-based document to a guidance document.

DOE issued a series of implementation guides (IGs) covering a variety of radiation-related topics. The IGs are designed to provide acceptable methodologies that comply with 10 CFR 835. The IG entitled *Workplace Air Monitoring* (G-10 CFR 835/E2 - Rev. 1) offers detailed guidance in this topical area. This IG offers particularly relevant information regarding CAMs. In addition, IGs entitled, *Internal Dosimetry Program* (G-10 CFR 835/C1- Rev.1) and *External Dosimetry Program* (G-10 CFR 835/C2 - Rev. 1) are germane to this competency.

DOE/EH-0173T, *Environmental Regulatory Guide for Radiological Effluent Monitoring and environmental Surveillance,* describes the elements of an acceptable effluent monitoring and environmental surveillance program for DOE sites possessing radioactive materials. These elements are applicable to all DOE and contractor activities for which the DOE exercises environmental, safety, and health responsibilities and are intended to be applicable over the broad range of DOE facilities and sites.

The primary purpose of this regulatory guide is to specify the necessary elements for effluent monitoring and environmental surveillance of radioactive materials at DOE sites in order to comply with both applicable Federal regulations and DOE policy. The high-priority radiological effluent monitoring and environmental surveillance program elements contained in this document are given in the form of generic performance criteria (i.e., the numeric limits and actions required for maintaining and operating an acceptable radiation protection program for the public and the environment). It also contains guidance to help define how the performance criteria can be met and includes specific actions, equipment selections, and operational methods that would be expected to meet the performance requirements.

Liquid and airborne effluent monitoring is specifically addressed in Chapters 2 and 3, respectively. These chapters provide guidance regarding these particular process monitors.

DOE Order 5480.22, *Technical Safety Requirements*, refers to those requirements that "define the conditions, safe boundaries, and the management or administrative controls necessary to ensure the safe operation of a nuclear facility and to reduce the potential risk to the public and facility workers from uncontrolled releases of radioactive materials or from radiation exposures due to inadvertent criticality."

DOE requires that nuclear facilities (both reactor and nonreactor) operate using approved Technical Safety Requirements (TSRs). TSRs were formerly known as Operational Safety Requirements (OSRs) for nonreactor nuclear facilities and Technical Specifications for reactor facilities.

Radiation Monitoring Systems

Radiation monitoring systems consist of several different types. Included in this category are CAMs, ARMs, portable and fixed-location personnel monitors, process monitors, and criticality monitors.

Continuous Air Monitors (CAMs)

10 CFR 835.403(a)(1) requires air sampling in the workplace when, under typical conditions, an individual would be likely to receive an annual intake of two percent or more of the specified annual limit on intake (ALI) values. The two percent value equates to an annual dose equivalent of 100 mrem. To assist in satisfying this requirement, CAMs are routinely used at DOE facilities.

The overriding purpose for using CAMs is to detect the presence of airborne radioactivity. CAMs are devices designed to continuously sample and measure the air for radioactivity. These devices provide real-time monitoring capability. Under 10 CFR 835.403(a)(2), real-time air monitoring must be performed in normally occupied areas for one or both of the following situations: where an individual is likely to be exposed to a concentration of airborne radioactivity exceeding one derived air concentration (DAC) for the radionuclide of interest or where there is a need to alert potentially exposed individuals to unexpected increases in airborne radioactivity levels.

At DOE facilities, the emphasis in the occupational setting is often devoted to detecting the presence of alpha-emitting transuranics such as plutonium, americium, etc. Beta CAMs are also used. If a preset exposure level is exceeded, possibly due to an unplanned release, modern CAMs are designed to activate an alarm system with the intent of reducing occupational exposures. CAMs should be designed to respond in the shortest possible time and at the lowest detectable level of radioactivity, keeping in mind the need to reduce, and preferably avoid, spurious alarms. Alarm capability and adequate sensitivity are requirements mandated in 10 CFR 835.403(a)(3).

Issues related to the use of CAMs include, but are not limited to:

- Design features
- Appropriate placement locations
- Choice of filter media
- Particle size dependence
- Flow rate measurements
- The ever-present problem of dealing with the presence of naturally occurring airborne radioactivity

General Principle of Operation

CAMs basically function by employing a flow system to steadily draw air, containing radioactive particulates, gases, or vapors, into the monitor. Particulates are deposited on some sort of collection substrate. For alpha radioactivity measurements, solid state detectors (typically a surface barrier or diffused junction semiconductor) work in concert with a multichannel analyzer (MCA) to detect, record, and identify the radionuclide(s) of interest, and analyze the energy distribution. Zinc sulfide (ZnS) scintillators are also used, but for detection purposes only.

Beta particulate CAMs primarily employ gas proportional counters and/or silicon surface barrier detectors to record radiation events. Air monitors utilizing beta (plastic) scintillators, Geiger-Müeller (G-M) detectors, and ionization chambers are being phased out, principally because of problems associated with radon progeny rejection. Those monitors employing G-M detectors tend to be larger and heavier than other CAMs because of the shielding materials required to reduce the background radiation levels.

Radioactive gases and vapors containing beta emitters are primarily collected using proportional counters and beta scintillators. Ionization chambers have also been used, but only for tritium, a radioactive gas. The larger the chamber, the more sensitive the measurement becomes.

Most CAMS separate airborne particulates through the filtration process where a physical barrier (a filter) removes particulates from the air stream. To a lesser extent, the process of inertial impaction--the removal of particulates that due to their inertia cannot make a bend in the air stream and are therefore impacted--is used in some CAM designs. Inertial impactors either deposit the particulates on a detector or on a collection substrate placed over the detector.

DOE CAM Requirements/Recommendations

Requirements established by DOE under 10 CFR 835 regarding CAMs have been discussed previously. In addition, the *Radiological Control Manual*, Chapter 5, contains several recommendations concerning their use (and that of other air-monitoring devices). Article 551, in the *Radiological Control Manual*, notes that radiological monitoring of airborne radioactivity should be conducted to characterize workplace conditions; to verify the effectiveness of physical design features, engineering controls, and administrative control; and to identify areas requiring postings. In addition, Article 555 offers additional recommendations including:

- Air monitoring equipment should be used in situations where airborne radioactivity levels can fluctuate and early detection of airborne radioactivity could prevent or minimize inhalation of radioactivity by personnel. Selection of air monitoring equipment should be based on the specific job being monitored. Air monitoring equipment includes portable and fixed air sampling equipment and CAMs.

- CAM equipment should be installed in occupied areas where a person without respiratory protection is likely to be exposed to a concentration of radioactivity in air exceeding one DAC or where there is a need to alert potentially exposed workers to unexpected increases in the airborne radioactivity levels.

  NOTE: 10 CFR 835 does not mention the phrase "...without respiratory protection..."

- Air sampling equipment should be positioned, where possible, to measure air concentrations to which persons are exposed. Alternative methods should be used when this cannot be accomplished.

- Air monitoring equipment should be routinely calibrated and maintained at a frequency of at least once per year. CAMs should be capable of measuring one DAC when averaged over eight hours (eight DAC-hrs) under laboratory conditions.

NOTE: The statement concerning the eight DAC-hrs recommendation does not appear in 10 CFR 835.

- CAM equipment recommended by Article 555.3 should have alarm capability and sufficient sensitivity to alert personnel that immediate action is necessary in order to minimize or terminate inhalation exposures.

- The proper operation of CAM equipment should be verified daily by performing an operational check. Operational checks should include positive air-flow indication, non-zero response to background activity, and internal check sources or 60 Hz electronic checks when available. CAM equipment operation should be verified weekly by checking for instrument response with a check source or with ambient levels of radon and thoron daughters.

At DOE facilities, the presence of transuranic materials (notably plutonium) is a concern due to inhalation hazards. As noted previously, continuous real-time monitoring is required when an individual could be exposed to airborne radioactivity concentrations exceeding the DAC for the radionuclide of interest. The CAM must be equipped with alarms and sufficient sensitivity to quickly alert potentially-exposed occupational workers that action is required to reduce or end an inhalation exposure.

Area Radiation Monitors (ARMs)

ARMs are utilized to control radiation exposures in a workplace setting. A variety of ARM systems exist. Emphasis is typically placed on the detection of gamma radiation intensities throughout the facility. To satisfy that objective, ARMs are either wall-mounted or operated as a freestanding unit in areas requiring monitoring. These devices tend to be fairly rugged and versatile, yet compact and lightweight. G-M or ionization chamber detectors are typically used. Depending on the detector, energy compensation is provided to allow a flat roentgen response versus gamma energy. Radiation levels ranging from 0.01 mR/hr up to 10,000 R/hr are typical. ARMs are designed to provide normal/fail indicators for safe operation; remote indicators that include meter, audible, and visual alarms. High radiation alarms and alarms designed to "alert" the worker that an alert level has been exceeded can be set over the entire meter range. Audible alarms often consist of a horn; visual alarms employ a light or beacon, which may flash on and off depending on the design.

From a regulatory perspective, the use of stationary (area) or portable radiation instrumentation for the purpose of measuring ambient radiation dose rates is required under 10 CFR 835.403(b).

The DOE *Radiological Control Manual* (Article 553) recommends that:

- ARMs should be:
  - Installed in frequently occupied areas where the potential exists for unanticipated increases in dose rates.
  - Also placed in remote locations where a need for local indication of dose rates prior to personnel entry exists.
  - Used to measure only the radiation for which the calibration is valid.
  - Tested at least quarterly to verify audible alarm system operability and audibility under ambient working conditions and operability of visual alarms when so equipped.
- The need and placement of an ARM should be documented and assessed when changes to facilities, systems, or equipment occur.
- Where an ARM is incorporated into a safety interlock system, the circuitry should be such that a failure of the monitor should either prevent entry into the area or prevent operation of the radiation-producing device.
- ARMs should not be substituted for radiation exposure surveys in characterizing a workplace.
- If installed instrumentation is removed from service for maintenance or calibration, a radiation monitoring program providing at least equal detection capability should be maintained, consistent with the potential for unexpected increases in radiation dose rates.

Process Radiation Monitors

Process radiation monitors are designed to detect concentrations of liquid and gaseous radioactivity in work areas, stacks, ducts, laboratories, etc. A variety of these systems exist and are routinely used as indicators of both normal and abnormal system operating conditions. They may also provide an estimate of the quantity of radioactivity released to the environment.

DOE EH/0173T, *Environmental Regulatory Guide,* addresses liquid and gaseous effluent monitoring in Chapters 2 and 3, respectively. Both chapters are intended to assist each DOE-controlled facility in meeting the requirements of DOE Order 5400.1, *General Environmental Protection Program Requirements,* and DOE Order 5400.5, *Radiation Protection of the Public and the Environment.*

Chapter 2 discusses general criteria and monitoring requirements, performance standards for liquid effluent monitoring systems, sampling and monitoring systems design criteria and considerations, alarm levels, and quality assurance.

Monitoring of liquid wastes should be performed to:

- Demonstrate compliance with DOE Order 5400.5 (specifically Chapter 2).
- Quantify radionuclides released from each discharge point.
- Alert appropriate personnel of "upsets" in processes and emissions controls.

Four basic sampling alternatives are noted in the regulatory guide:

- Off-line periodic - grab samples of waste streams are taken on a periodic basis, concentrated (if needed), and delivered to the laboratory.
- Off-line sequential - time aliquots of the effluent are taken when a relatively constant waste stream flow rate is present.
- Off-line proportional - known fractions of the effluent are collected on a continuous basis prior to laboratory analysis.
- Off-line continuous - samples are continuously collected at a known uniform rate.

In the laboratory, the presence of alpha, beta, and gamma radioactivity in liquid effluents can be determined in different ways. For example, the sample can be placed in a stainless steel vessel holding approximately 20 to 25 liters of water. Various detectors are utilized to detect the radioactivity. Alpha and beta radiations, for instance, can be detected using proportional or liquid scintillation counters while gamma radiation is detected with sodium iodide (NaI) scintillators. These monitors tend to be quite heavy, often weighing 2,000 to 3,000 pounds.

Chapter 3 of the *Environmental Regulatory Guide* is devoted to airborne effluent monitoring. This chapter begins by stating that airborne emissions from a DOE-controlled facility should be evaluated and assessments made of the potential for release of radioactivity. This assessment is important in that it directly impacts the preparation of the site's effluent monitoring and environmental monitoring programs (discussed in DOE Orders 5400.1 and 5400.5, respectively).

The regulatory guide recommends that airborne emissions, having the potential for causing doses exceeding 0.1 mrem effective dose equivalent (EDE) to a member of the general public (under a realistic scenario) from emissions in a year, should be monitored. Chapter 3 describes various aspects of airborne effluent monitoring. These include general criteria and monitoring requirements, requirements for compliance with EPA regulations, performance standards for air sampling systems, design criteria for system components, point-source design criteria, alarm levels, and quality assurance (QA).

The following table taken from the regulatory guide lists the criteria for establishing an airborne emission monitoring program. The scope of the monitoring effort is dependent on the impact of the sources and the potential for accidental releases.

Criteria for Emission Monitoring	
Calculated Maximum Dose from Emissions in a Year to Members of the Public: H_E mrem (effective dose equivalent[(EDE])	Minimum Emission Monitoring Criteria*
$H_E \geq 1$	1. Continuously monitor emission points that could contribute $\geq$0.1 mrem in a year 2. Identify radionuclides that contribute $\geq$10% of the dose 3. Determine accuracy of results (±% accuracy and % confidence level) 4. Conduct a confirmatory environmental survey annually <u>or</u> Monitor at the receptor: 1. Continuously sample air at receptor 2. Collect and measure radionuclides contributing $\geq$1 mrem (EDE) above background 3. Establish sampler density sufficient to estimate dose to critical receptor given typical variability of meteorological conditions 4. Obtain prior approval from EPA
$0.1<H_E<1$	1. Continuously monitor emission points that could contribute $\geq$0.1 mrem in a year 2. Identify radionuclides that contribute 10% or more of the dose 3. Conduct confirmatory effluent monitoring at emission points where possible 4. Conduct a confirmatory environmental survey every few years
$H_E < 0.1$	1. Take periodic confirmatory measurements 2. Test to determine need to monitor by calculating dose (H_E) for normal operation, assuming that the emission controls are inoperative 3. Conduct a confirmatory environmental survey at least every five years

*Alternative criteria may be obtained through EH following coordination with EPA.

Several types of instrumentation are utilized at DOE facilities for the measurement of specific airborne radionuclides. These include tritium monitors, ionization chambers (for gaseous tritium), radioiodine monitors, noble gas monitors, gross alpha and beta monitors, transuranic radionuclide monitors, uranium monitors, and particulate fission and activation product monitors. Each of these monitors have its own design features and capabilities.

Personnel Monitors

Personnel monitors are designed to determine the amount of radioactivity that might be present on personnel--in their excretions, or on their skin, or on any part of their clothing. 10 CFR 835, Subpart E, requires workplace monitoring. Section 835.401 lists the general requirements for workplace instrumentation including:

- The need for periodic maintenance and calibration.
- The choice of appropriate instrumentation for the type(s), levels, and energies encountered.
- Consideration of environmental conditions the instrument(s) would be exposed.
- Determination/confirmation of the operability of the instrument.

While the use of portable instrumentation is an important component of contamination control, emphasis should also be placed on the use of fixed (stationary) personnel contamination monitors. These devices are typically designed to allow the user to place his/her hands and feet in the monitor ("hand and foot" monitors), wait for a sufficient period of time to achieve sufficient sensitivity, and then inform the individual as to whether he/she is free of contamination. Visual and audible alarms are utilized to relay the contamination status to the individual. These monitors are meant to signal the presence of radioactivity, not necessarily the exact location. If contamination is found, portable radiological instrumentation can localize the area of contamination and facilitate decontamination procedures. Large area detectors are in use that allow the detection of contamination over a much larger area of the body.

Fixed personnel monitors primarily employ gas-flow proportional counters and fixed volume (gas-filled) G-M detectors to detect alpha, beta, and gamma radiation. Thin mylar windows are required to allow detection capability, especially in the case of alpha particles. In some cases, solid-filled scintillation detectors are used for detection of alpha radiation.

These monitors should be placed at strategic locations in the facility. Common locations include egress points from radiologically controlled areas where contamination could potentially exist. The number of monitors is influenced by the number of work stations and the locations where higher contamination levels are found.

Contamination Surveys

10 CFR 835.404 addresses the requirements for radioactive contamination control and monitoring. The instrumentation selected must be able to satisfy the requirements of 10 CFR 835. The Radiological Control Manual, (Chapter 5, Part 5) addresses the need to perform contamination surveys. In short, good health physics practices dictate the need to evaluate the extent of any radiological hazards that may be present.

Radioactive contamination can reside on surfaces (floors, walls, ceilings, etc.) and/or in the air; it can be detected in a variety of ways. Levels of surface activity, that is, radioactivity found on building or equipment surfaces, are detected initially by taking direct measurements. These measurements are performed using portable survey instrumentation appropriate for the type and energy of radiation. The instrumentation is placed over the area of interest and a reading taken. The result is considered to be a measure of the total surface activity because the instrument cannot differentiate between fixed and removable contamination.

Fixed contamination refers to radioactivity that is not readily removed from a surface. However, actions such as grinding, sanding, or leaching of the material over time accelerates its removal. Removable (also known as "loose" or "transferable") contamination refers to contamination easily transferred to another surface. Removable contamination, in general, is more of a hazard because of the potential for entering the respiratory pathway. The level of removable contamination is estimated by taking a smear (or wipe) sample over a typical surface area approximating 100 cm^2: 10 centimeters (cm) by 10 centimeters or 4 inches by 4 inches.

Airborne contamination results from the presence of radioactive materials in the air. This can occur via resuspension of loose surface contamination, opening contaminated valves, grinding, fires, etc. Resuspension of loose surface contamination is a serious concern because inhalation of these suspended particulates is a major route of entry into the body.

Contamination Control

Chapter 2 (Part 2) of the *Radiological Control Manual* states that contamination control "is achieved by using engineering controls and worker performance to control contamination at the source, reducing existing areas of contamination and promptly decontaminating areas that become contaminated." Engineering controls include the use of ventilation and containment systems--systems consisting of structures or components designed to minimize or prevent the release of radioactive materials. In general, ventilation systems are designed to move any potential airborne contamination away from personnel and to filter the radioactive material from the air. Containment systems are used to physically enclose radioactive material, thereby preventing it from being released. Administrative controls are used to direct the actions of personnel in order to minimize the risk of exposure to radioactive contamination. Worker contamination control practices are measures taken to use personal protective equipment to prevent personnel from becoming contaminated with radioactive material.

Radiation Protection from Internal Sources

Ionizing radiations constitute both internal and external hazards. For potential internal radiation hazards, the primary objective is to avoid taking in any radioactive materials into the body.

Deposition of radioactive material in the body can occur through four mechanisms or pathways:

- Inhalation - breathing in radioactive material
- Ingestion - eating or drinking radioactive material
- Absorption - radioactive material absorbed through the skin
- Injection - radioactive material entering the body through punctured skin

The extent of the hazard from internal contamination depends on the radionuclide involved, the type of radiation and its energy, the length of time required for the radioactive material to diminish in activity through a combination of radioactive decay and body elimination, the radiosensitivity of the organ(s) exposed, and the amount of the radionuclide in the body. Radionuclides that decay by alpha and beta emission are considered the most dangerous from an internal hazard point of view.

Preventing the entry of radioactive material into the body can be accomplished, to a great extent, by utilizing containment and confinement techniques along with cleanliness to minimize the risk of intake through inhalation, ingestion, injection, or open wounds.

Recommendations to accomplish this include:

- Segregating potentially radioactive areas (laboratories, counting rooms, ventilation systems, etc.) from nonradioactive locations.
- Minimizing access to unauthorized personnel.
- Working with the smallest quantity of radioactive material whenever practical.
- Choosing materials of low toxicity.
- Eliminating food, drink, chewing, and smoking materials in potential or known radioactive material areas.
- Avoiding handling potentially contaminated equipment with bare hands.
- Wearing the prescribed protective clothing when working in a radioactive materials area and following the proper procedure for removing potentially contaminated clothing.
- Routinely washing hands and performing contamination monitoring (e.g., frisking) for the detection of possible contamination.
- Promptly decontaminating the skin using appropriate techniques (and trained personnel, if required).

These examples serve to reiterate the fact that engineering controls, administrative controls, and personnel work practices are fundamental aspects of a good contamination control program.

Corresponding to the four intake pathways by which radioactive material can enter the body, there are four elimination pathways (listed in the general order of importance):

- Urinary excretion
- Fecal excretion
- Exhalation
- Perspiration

Determining the internal dose received by a worker is often a complex process. One methodology for accomplishing this requires bioassays where particular biological samples are collected and analyzed; internal dose calculations are then performed. Types of samples collected include urine and fecal samples and nasal smears. The type of sample collected and the internal dose received, are dependent upon many physical and biological factors.

Routine bioassay programs are required by 10 CFR 835 for radiological workers, declared pregnant workers, minors, and members of the public if an intake of radioactive material occurs exceeding specific dose limits noted in §835.402 (c). The DOE *Radiological Control Manual* offers guidance regarding internal dosimetry programs in Chapter 5, Part 2, Articles 521-523.

Whole-body counting provides data for the assessment of internal exposure to photon-emitting radionuclides. Biological samples are not collected. A variety of radiation detectors, including NaI, combination NaI and cesium iodide (phoswich), and intrinsic germanium are positioned over the body to detect characteristic photons emitted from particular radionuclides. The detectors are often placed to detect radioactivity emitted from the whole body or from a localized portion of the body. Lung counters, for example, are used to detect inhaled radioactive material in the lungs. They are widely used at DOE facilities to assist in the detection of inhaled uranium (U) and plutonium (Pu).

Personal protective equipment (PPE) is designed to protect the worker from ionizing radiation hazards in the workplace. In particular, internal contamination concerns (the inhalation, ingestion, etc., of radioactive materials) receive a great deal of attention. For this situation, respiratory protection is used when engineering controls and work practices are deemed to be insufficient. The *Radiological Control Manual* (Chapter 5, Part 3) suggests the use of respirators with particulate or gas-filtering cartridges, supplied air respirators, self-contained breathing apparatus (SCBA), and airline supplied air suits and hoods. Protective clothing is used as a contamination control measure for protection from skin contamination. The *Radiological Control Manual* (Chapter 3, Appendix 3C) discusses the selection and removal of protective clothing. In addition, safety glasses may be required to protect the eyes from beta radiation. The hazards from photon radiations (e.g., potential damage to the reproductive organs and skin irradiation/contamination) can be reduced somewhat by employing shielding in the form of lead-lined aprons and gloves. DOE facilities utilize radiation work permits (RWPs) and area postings as a means to communicate the requirements for PPE.

Radiation Protection from External Sources

Adequate protection against excessive exposures to external sources of radiation can be provided by primarily employing three major exposure reducing principles: time, distance, and shielding, and utilizing the As Low As Reasonably Achievable (ALARA) philosophy.

The control of exposure time (time spent in a radiation field) is the first major health physics principle available to an occupational worker to limit his/her exposure to an external radiation source. It is important to realize that the radiation dose received by the worker is directly proportional to the time spent in a radiation field. Therefore, to minimize the dose received, the time spent in the radiation field must be accordingly reduced. The control of exposure time is a significant factor in the issuance of RWPs common at DOE facilities.

A very common and extremely effective technique to reduce personnel exposure is to increase the distance between the worker and the radiation source. In many instances, this approach is more important than controlling exposure time and can be easily demonstrated for "point" (small) sources of radiation. While the exposure-time relationship follows a direct dependence (i.e., reducing the time spent in a radiation field by one-half reduces the exposure to the worker by one-half), distance dependence often follows the "inverse-square" (second power) law. Thus, doubling the distance from a point source reduces the exposure to the worker by a factor of four. It should be noted that situations do exist where the inverse square law does not apply. In these cases, the relationship between the dose received and the distance from the source does not always follow a simple rule.

A third factor for controlling external exposures entails the use of shielding. Shielding the source of radiation becomes important when minimizing time and maximizing distance are not sufficient to reduce personnel exposures to acceptable levels. Determining the required shielding is influenced strongly by the type (alpha, beta, gamma, x-ray, neutron) and the energy of the radiation.

Doses received from external radiation sources can be evaluated by calculating the length of time spent in a radiation field of known intensity through radiation monitoring; or using personnel dosimeters. The use of personnel dosimeters is one of the most important aspects of an external dosimetry and personnel monitoring program--a program designed to not only detect, but measure (dosimetry) and evaluate individual exposures to ionizing radiation.

Personnel monitoring devices can be defined as devices designed to be worn or carried by an individual for the purpose of measuring the dose received. Personnel dosimeter measurements are considered the preferred source of information for evaluating external doses (relative to workplace monitoring programs or other personnel monitoring programs). Examples of primary personnel monitoring devices (that is, those typically used for the measurement of the dose equivalent received) include thermoluminescent dosimeters (TLDs), film, and track etch dosimeters. Audible-alarm dosimeters, electronic dosimeters, and pocket ionization chambers are examples of supplemental dosimetry--devices often worn with or located near the primary dosimeter. Be aware that some of these devices should not be used for the purpose of officially recording the dose to a worker. A brief description of one primary dosimeter (TLD) and one supplemental dosimeter (pocket ionization chamber) follows.

Thermoluminescent Dosimeters

When certain materials (e.g., NaI, ZnS) are exposed to ionizing radiation, they absorb at least some of the radiation's energy and immediately release this energy as light. This process is known as scintillation. For each particle or photon of radiation interacting with the scintillating material, a flash of light is produced. The greater the energy absorbed by the material, the brighter the flash.

With other materials such as lithium fluoride (LiF) or calcium sulfate ($CaSO_4$), much of the absorbed energy is trapped rather than released immediately. Later, heating the material can cause this trapped energy to be released as light in a process called thermoluminescence. Materials with this property are referred to as TL materials. The amount of energy absorbed by a material reflects the absorbed dose, and since the intensity of the emitted light is a measure of the absorbed energy, TL materials can function as integrating dosimeters.

Thermoluminescence is essentially a two stage process:

- The radiation energy is absorbed and trapped in the TL material.
- The trapped energy is released in the form of light when the TL material is heated.

A photomultiplier tube is used to convert the light pulses into an electronic signal, which is subsequently displayed as a count rate. In the workplace, TLDs are used to measure the external radiation dose received by workers. TLDs can be used to assess the whole body dose or the dose to other parts of the body. TLDs are typically used to detect beta, gamma, or neutron radiation.

Pocket Ionization Chambers

Direct reading pocket dosimeters are small ionization chambers (typically the size of a pen) that contain a quartz fiber electroscope. They operate on the principle of ionization and are capable of responding to gamma and high energy beta radiation as well as neutrons, if appropriately modified. Various ranges are available; however, 0 to 200 mR is probably the most common range utilized.

These devices contain a fixed and a movable quartz fiber, which, initially, are similarly charged, forcing them to repel. As radiation enters the chamber and ionizes the air, the charge is neutralized on the fibers and they move closer together. The degree of movement, and hence the exposure, is visualized by observing a hairpiece (movable fiber) through an eyepiece. The term direct reading, therefore, comes from the fact that the individual can estimate the exposure at any time by holding the pocket dosimeter up to a light source and directly reading the value off a numerical scale. This constitutes an advantage over TLDs and allows the worker to keep track of his/her exposure. Disadvantages associated with these devices include their fragility (can go offscale if dropped) and expense. Pocket ion chambers are typically worn adjacent to whole-body TLDs.

Nuclear Accident Dosimeters (NADs)

Nuclear accident dosimeters (NADs) are monitoring devices that measure the level of neutron radiation. These dosimeters typically contain foils that measure the induced radioactivity present after exposure to neutrons of various energies. In general, these dosimeters are required for personnel at DOE facilities who could come in contact with fissile materials present in sufficient quantity and kind to potentially constitute a critical mass or where exposures from a nuclear accident are possible.

In addition to nuclear accident dosimeters, nuclear criticality accident alarms and alarm systems exist for alerting personnel to promptly evacuate the area to reduce the risk of exposure to radiation. Generally, the nuclear criticality accident alarm system is meant to prevent large exposures to many people. Criticality alarm systems are usually composed of neutron or gamma radiation detectors and annunciation (signal) equipment. In addition, administrative procedures are needed to ensure that the equipment is maintained and properly calibrated.

3. SELF-STUDY SCENARIOS/ACTIVITIES AND SOLUTIONS

Scenario 1

An operator at a DOE facility inadvertently de-energized electrical panels that supplied power to several effluent-stack sampling pumps. As a consequence, the sampling pumps were off-line for two hours before power was restored.

What are some concerns raised by this situation?

Scenario 2

A radiological control technician (RCT) performing routine surveillance activities noted low air-flow rates on several alpha continuous air monitors. After notifying the shift manager and posting the room in accordance with the facility's radiological operating instructions, the RCT performed a closer examination of the air monitors.

1. What possible reasons can you cite for the observation of low air flows?

2. Why is it important to have properly operating air monitors at facilities handling radioactive materials?

3. What recommendations can you offer to prevent or minimize this particular problem?

Scenario 1, Solution
(Any reasonable paraphrase of the following is acceptable.)

For many DOE facilities, de-energizing effluent-stack sampling pumps constitutes an operational safety requirement (OSR) violation. The OSR may require continuous monitoring of radioactive material effluents. DOE Order 5480.22, *Technical Safety Requirements,* states that operational safety requirements/technical safety requirements represent the minimum acceptable controls to ensure safe operation.

Unplanned shutdowns are a concern because personnel safety and safe operation of the facility can be adversely impacted. Air quality personnel should determine as soon as possible whether stack emissions exceeded acceptable levels.

Scenario 2, Solution
(Any reasonable paraphrase of the following is acceptable.)

Two common reasons as to the cause of the low air-flow rates include the loading of dust on the filters--a situation that could be aggravated under higher dust conditions--and improper flow-rate settings on each CAM (though this may be somewhat unlikely considering several CAMs experienced the problem in this scenario concurrently).

The setting of proper air-flow rates is important in the context of controlling worker intakes to radioactive material. Routine surveillance goes a long way in allowing facilities to detect, control, and minimize the risks associated with equipment failures.

The following recommendations should assist work planners at DOE facilities in preventing or minimizing this problem from reoccurring:

- Adding a check point in their procedures to verify that a work activity does not impact the operation of local air monitors.
- Being alert to conditions that can degrade the operability of air monitors and implementing compensatory measures as needed.
- Incorporating new information into future work planning sessions.
- Temporarily increasing filter change-outs during conditions that create high dust conditions.

4. SUGGESTED ADDITIONAL READINGS AND/OR COURSES

Readings

- Argonne National Laboratory. (1988). *Department of Energy Operational Health Physics Training* (ANL-88-26). Argonne, IL: Author.
- Cember, Herman (1996). *Introduction to Health Physics* (3rd ed.). McGraw-Hill: New York.
- Gollnick, D. A. (1988). *Basic Radiation Protection Technology* (2nd ed.). Pacific Radiation Corporation: Altadena, CA.

Courses

- *Nuclear Physics/Radiation Monitoring* -- DOE.
- DOE/EH-0450 (Revision 0), *Radiological Assessors Training (for Auditors and Inspectors) - Fundamental Radiological Control,* sponsored by the Office of Defense Programs, DOE.
- *Applied Health Physics* -- Oak Ridge Institute for Science and Education.
- *Health Physics for the Industrial Hygienist* -- Oak Ridge Institute for Science and Education.
- *Safe Use of Radionuclides* -- Oak Ridge Institute for Science and Education.